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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 494

"SAFETY" FUELS FOR AIRCRAFT ENGINES

By A. Grebel

From "Memoires et compte rendu des
travaux de la Société des Ingénieurs Civils de France
July-August, 1927

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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"SAFETY" FUELS FOR AIRCRAFT ENGINES.*

By A. Grebel.

In reading the daily papers, engineers, like all other readers, are saddened by the lengthening list of aviation martyrs. They are doubtless disturbed even more than others by the repetition of accidents due, among other causes, to conflagrations on airplanes during flight or in unfortunate landings.

Several of my colleagues, Barbet, Cuvelette, Ferrus, Guise-
lin, Laubeuf and Peridier, were called upon to investigate fuels
for assaulting cars ("tanks") and airplanes, on two of the num-
erous advisory committees created during and after the war.
The last subcommittee was discharged in 1922 for various reasons,
one of these being, as reported to us by Guiselin, the impossi-
bility of determining the real causes of fires on airplanes.
This difficulty would have justified the retention of this group
of competent and independent investigators until this problem
were solved.

We know that the combustion of the vapors, caused by a
spark or back fire to the carburetor, is frequently propagated
by the oil and dirt covering the engine and is thus communi-
cated to the fuel, when the tanks burst from the heat or are

*"Les carburants de 'sécurité' en aviation," from "Memoires et
compte rendu des travaux de la Société des Ingenieurs Civils
de France," July-August, 1927, pp. 803-821.

broken open by a shock. An unnoticed fuel leak may also lead to the ignition of the fuel by its coming in contact with red-hot exhaust pipes..

Brunat, of the S.N.Aé. (Service de la Navigation Aérienne), gave, in his lectures of February 24, and October 20, 1926, statistical data showing the gravity and frequency of the various causes of fire on airplanes. According to Brunat, 28% of the fires during flight are due to back fires to the carburetor, 24% to the breaking of connecting rods, causing either a back fire or the direct ignition of the oil in the crank case. Fires on the ground are frequently due to back fires coincident with breaks in the piping, rarely with the bursting of the tanks. The back fires are caused by sudden variations in the engine speed, following, for example, the breaking of the propeller in landing, or a pick-up during stunt flights. Hand fire extinguishers are of little use. As to emptying the fuel tanks before an anticipated fire, we do not consider it worth any extended investigation.

If fire safety is not to be acquired at the expense of the functioning reliability of the engine, we must try to burn fuels which are less inflammable at their temperature of utilization. We will explain further on why we underline "utilization."

Definitions.-- First of all it seems desirable to define the term "fuel." In fact, this term is now extended to include rich gases compressed in cylinders, the calcium-carbide acetylene generator, charcoal, wood, various briquets convertible into poor gas. It has even been maintained that vapor obtained from coke and electricity generated by "white coal" (water power) and accumulated in storage batteries are veritable fuels. Of course these expedients, already old, imply the replacement of gasoline engines simultaneously with the replacement of gasoline.

When we began the investigation of carbureted air, or air gas, 25 years ago, we used very volatile carbonaceous liquids, like gasoline, ether, and mixtures of light oils and benzol.* The problem was to carburet the air even at temperatures slightly below 0°C (32°F) in such a way as to form a rich nonexplosive mixture, with a very low dew point, i.e., distributable through pipes. At that time the carburetors of automobile engines used only volatile liquids (gasoline, benzol, carbureted alcohol) possessing a vapor tension high enough to form an explosive mixture of air and vapor holding in suspension only very small droplets and vesicles. The problem of heating the fuel diffuser arose from the desire to use alcohol, which is but slightly volatile and carbureting and of low vapor tension,

*See "Etude sur les appareils doseurs à air carburé" in the Journal de l'Eclairage au Gaz, from November 20, 1907, to January 5, 1908.

and even nonvolatile kerosene.*

At the present time we use liquid fuels, whose heavy tailings are not volatile, without heating the carburetor otherwise than by the heat accumulated under the hood of the vehicle. There is introduced into the cylinders a very coarse mist charged with large drops of liquid, which are sufficiently vaporized, however, at the end of the compression stroke for the combustion not to be too incomplete. The obsession for obtaining the maximum power is so great that those wishing to use, for economy or safety, fuels difficultly inflammable at ordinary temperatures, try to do so without heating the mixture of air and atomized fuel, so as not to reduce the weight, or, if preferred, the thermal potential of the cylinder charge. They are not only illogical, but they impair the mean thermal efficiency.

We can very well use in present gasoline engines, with moderate and appropriate compression ratios, all combustible liquids whose tailings distill below $225-240^{\circ}$ and which begin to distill between 30 and $175-190^{\circ}$ as the maximum. Graphically (Fig. 1) this amounts to saying that the possible fuels are represented by distillation curves situated to the left of the oblique line A A'. This last deliniation can also be translated

*	Alcohol	Gasoline	Benzol
Carbureting power per kg (m^3 of air)	7.0	11.7	10.4
Weight of vapor per m^3 (kg)	2.0	3.9	3.5
Vapor tension of perfect mixture	49.2	16.5	20.0
" " at $20^{\circ}C$ (mm of Hg)	51.0	296.0	122.0

by a flashing point (open-cup test) between 40 and about 85° for hydrocarbons. Though it is always necessary to maintain a temperature above 0°C in the spraying nozzle in order to avoid frost, heating the mixture before its entrance into the cylinders is neither necessary nor beneficial for the methyl series of hydrocarbons when the Engler boiling point does not exceed 70°C. It is advantageous, however, from the standpoint of specific fuel consumption, for aromatic hydrocarbons which begin to boil at 80° and can be increased 40-50° without excessively diminishing the maximum power.

For explosion engines having moderate compression ratios, speeds of several thousand R.P.M., normal piston speed, spark ignition, and carburetors capable of being heated, I think we can use liquid fuels, whose dry point in fractional distillation is below 240°C and whose vapor tension can be carried to 10-15 times its value in the explosive mixture, without heating the explosive mixture to temperatures capable of causing catalytic decomposition or partial combustion or excessive loss of power with respect to the fuel consumption.

Combustible liquids, in order to be satisfactory as fuels must also possess other qualities which we specified in the Genie Civil of April 4, 1926, pp. 334-338: namely, a limited oxygen content and a maximum hydrogen content; calorific concentration, by both volume and weight; high thermal potential;

fluidity and incongealability, stability and homogeneity; and suitable rapidity of combustion. Furthermore, the fuel itself and its combustion products must have no malodorous, toxic or corrosive properties. Lastly come questions of cost, disposability and source, which we will disregard for the moment.

In particular, for use in aviation in cold weather and at high altitudes, we must reject congealable liquids which deposit crystals capable of stopping up the filters and nozzles, or become viscous to the point of endangering the alimentation of the carburetor at low temperatures.

As to the so-called "safety" fuels, it is generally assumed, without further investigating the characteristics corresponding to this appellation in the case of explosion engines, that these are the fuels whose flashing points are below 40°C (104°F) 40-85°. This implies, as regards the alimentation of aircraft engines, a sort of advance assimilation in the case of benzine and "white spirits" used in paints and of petroleum products used for lighting. This is very debatable. If the surrounding temperatures are habitually such that the use, in painting and in lighting, of noninflammable liquids below 40°C gives perfect satisfaction, it is obvious that, the less inflammable a fuel is, the more the carburetor must be heated to insure perfect combustion in the engine, without fouling or smoke and that such heating lessens the degree of safety apparently assured by its being less volatile at ordinary temperatures.

Furthermore, in order to be forewarned against every illusion, let us note another great risk in the use of heavy fuels in carburetor engines, to which the attention of eventual users must be called. Misfires may not only diminish or prevent the heating of the carburetor, but may cause a considerable accumulation of unburned substances which contaminate the lubricating oil. High-speed engines in particular are thus very rapidly disabled. Such accumulations are troublesome and particularly dangerous in the case of airplanes and other swift vehicles. Aside from the fouling of the spark plugs (little to be feared with good carburetion and sufficient heat), a poor contact, defective insulation, the breaking of a wire, or failure of the magneto may cause misfires. Excessive cooling of the cylinders may cause similar troubles, although to a less degree.

These remarks are not made to discourage one from tackling the problem of "safety" fuels, but only to prevent his undertaking it in ignorance of the reefs to be avoided, if he does not wish to run aground.

We must also avoid going astray in seeking safety fuels among too light or too heavy liquids. Let us refer again to Figure 1. If the upper temperature limit for safety fuels is naturally the same as for fuels in general, say $190-240^{\circ}\text{C}$ (AA'), the lower limit may be set at $125-175^{\circ}\text{C}$ (BB'). In this parallelogram there must be inscribed all the Engler distillation curves for hydrocarbons whose flashing points in an open-cup

tester can be, as a corollary, above 40° and below 85° .

Flashing point.— We examined in detail, in the Genie Civil of April 9, 1927, this extrinsic characteristic of liquid fuels. The flashing point corresponds to the explosive combustion of the vapors emitted at the surface of the liquid fuel more or less cooled or more or less heated. The small flame produced goes out immediately. In reality, this point corresponds to the formation of a poorer mixture than the perfect explosive one. The following table shows that, for hydrocarbons, the flashing point corresponds to a vapor tension of 10–13 mm Hg in the flashing-point mixture, while the tension in the perfect mixture varies between 14 and 20 mm.

Pure substance	Hexane $C_6 H_{14}$	Methyl alcohol $CH_4 O$	Ethyl alcohol $C_2 H_6 O$	Benzene $C_6 H_6$	Heptane $C_7 H_{16}$	Toluene $C_7 H_8$	Xylene $C_8 H_{10}$
Boiling point at 760 mm Hg ($^{\circ}C$)	68°	64°	78°	80°	100°	111°	137°
Flashing point (Ormandy & Craven)	-26°	-1°	11°	-12°	-1°	10°	29°
Corresponding vapor tension (mm Hg)	9.8	27.6	25.6	12	11.4	12.8	11
Vapor tension in perfect mixture	16.2	92.3	49.2	20.4	14.1	17.1	14.7

Pure substance	Hexane $C_6 H_{14}$	Methyl alcohol $C H_4 O$	Ethyl alcohol $C_2 H_6 O$	Benzene $C_6 H_6$	Heptane $C_7 H_{16}$	Toluene $C_7 H_8$	Xylene $C_8 H_{10}$
Burning point (Ormandy & Craven)	1°	32°	32°	10°	17°	30°	50°
Corresponding vapor tension	48	162	82	45	31	38	33

We will not consider the testing apparatus, which is either open-cup or closed, nor the burning point (at which the liquid continues to burn after ignition). The table shows that the burning point corresponds to the vapor tensions and, consequently, to the hydrocarbon content of the carbureted air, which is much greater than that of the theoretically perfect mixture.

In adopting the approximate formula of Ormandy and Craven for pure substances, the initial boiling point t_e can be related to the flashing point t_i , by the imperfect formula for hydrocarbons $t_e = 1.36 (t_i + 72)$. This expresses the fact that the flashing point of the fuels depends on their volatility.

We consider, moreover, that the complete fractioning of heterogeneous combustible liquids is also instructive otherwise than the even simpler, although delicate, determination of the flashing point. It is, in fact, more interesting, with respect to the phenomena of combustion, to know the content of these liquids in light, medium, and heavy oils, than to know the vol-

atility of their first fractions, which, by elective evaporation, form the explosive mixture it is sought to ignite in the flashing-point apparatus. It is obvious that the light oils, if they are present only in a very small proportion, cannot appreciably lower the flashing point, especially if it is obtained with the open-cup tester.

However that may be, the degree of noninflammability is an arbitrary but convenient criterion of safety from the standpoint of ordinary fires. Its determination with the known commercial apparatus is susceptible of a practically adequate accuracy, if care is taken to designate the apparatus and the method of procedure.

Ignition temperature.— Although they have not yet been made the object of thorough, systematic investigation, true physico-chemical laws, specific for each carburetant, certainly combine their speed of reaction (oxidation by the air) with the temperature, pressure, and catalytic influences.

Although the speed of reaction in itself is imperfectly known, it is translated by extrinsic characteristics of more current use, such as limit of ignition, propagation speed of the flame, retarded ignition and ignition temperature or spontaneous ignition. This last phenomenon, which has not yet received sufficient attention, must obviously not be confounded with the flashing point, which is dependent on the volatility.

It indicates the lowest temperature at which the mixture of air and vapor ignites.

On the occasion of the first *Congres de Chauffage industriel* (Congress of Industrial Heating) in 1923, Taffanel published some data determined at the Lievin testing station, which were found in the experiment records not destroyed by the war. At the atmospheric pressure, pentane ignites at a minimum temperature of 512°C for a minimum content of 2-3%; pure benzene at 545° for 2%; pure toluene at 710° for 2%; an automobile gasoline at 481° for 2%; and a commercial benzol at 578° for 5%. English experimenters found a much higher ignition temperature (740°) with a benzol probably richer in toluene and xylene and with a different testing apparatus.

The pressure, which diminishes the ignition delay, also diminishes the rapidity of evaporation. These two effects, combined, tend to cause premature ignition and detonation.

According to French, English and German experimenters, it may be considered that the most common carburetants and fuels classify as follows, the temperatures given in round numbers indicating only the order of magnitude.

Approximate ignition	Toluene	Benzol	Gasoline	Gas Oil	Kerosene
temperature ($^{\circ}\text{C}$)	700	600	500	350	300

It is then explained that quite high compression ratios can be applied to gasoline and especially to benzol in engines with

carburetors and spark ignition; that kerosene cannot detonate because its temperature of complete evaporation is higher than its ignition temperature. It seems that the effect of the antidetonants must correspond to an elevation of the ignition temperature.

Likewise, it is obvious that the fuels for explosion engines must have high flashing points and that fuels with low ignition temperatures, like gas oil, must be reserved for fuel-injection engines (Diesel or semi-Diesel). It has long since been practically demonstrated that the maximum compression ratios for gases in explosion engines is about 1% of the ignition temperature. Any fuel with too low a flashing point (less than $400-450^{\circ}\text{C}$.), even if its distillation curve is included in the parallelogram AA'BB' of Figure 1, must be rejected as a safety fuel, since we would not consent to return to compression ratios below 4, which entail a poor efficiency.

The few figures we have cited show the superiority of benzol (benzene) over gasoline and more particularly of solvent naphthas over "white spirits."

Attention is again called to the fact that ignition by a very hot spark reduces, like the compression, the ignition delay or, more correctly, the ignition duration.

Heating the explosive mixture.— In the previous section we showed that the degree of heating of the explosive mixture

(and not of the liquid) should be adapted to the particular fuel. Heating by a few tens of degrees only slightly affects the propagation speed of the flame.

It is profoundly regrettable that constructors and many laboratory officials generally neglect to find the temperature of the explosive mixture before its entrance into the cylinders, as likewise the richness of the mixture and the composition of the exhaust gases. Discussions are heard on the effect of "strong" heating or "moderate" heating, when no one knows the temperature of the explosive mixture before admission, nor its composition, nor the degree of perfection of its ultimate combustion.

It is our opinion that, in order to obtain the full benefit of a fuel in a gasoline engine, it must be rendered equally combustible with gasoline inside the cylinders. We will adopt, in advance, a "safety factor," somewhat the same as in the strength of materials. For the lack of direct verification, in each case, of the best heating temperature corresponding to the minimum specific consumption t_r , we assume that the latter must be such that the corresponding mean vapor tension f_r is 10 to 15 times the theoretical vapor tension f in the perfect explosive mixture, for engines running at several thousand R.P.M.

$$f_r = 10 - 15 f$$

This rule can be expressed in a formula combining the best heating temperature t_r with the initial boiling point t_e of the pure substance:

Aromatic hydrocarbons,

$$t_r = 0.916 t_e - 0.0005 t_e^2 - 23;$$

Methyl hydrocarbons,

$$t_r = 0.896 t_e - 0.0005 t_e^2 - 29.$$

Figure 2 illustrates our conception of the adjustment of the heating to the nature of the hydrocarbons of the aromatic and methyl series. The group of slightly inclined dashed lines connect the points:

- A_0 , vapor tensions corresponding to perfect mixtures of aromatic hydrocarbons with air;
- A_1, A_2 , heating temperatures corresponding to vapor tensions ten and fifteen times as great;
- F_0 , vapor tensions corresponding to perfect mixtures of methyl hydrocarbons with air;
- F_1, F_2 , heating temperatures corresponding to vapor tensions ten and fifteen times as great.

Though the carbureting power of the hydrocarbons varies but slightly (10.5 to 12 m³ of air per kg), the density of their vapor increases with their boiling point, so that the rational heating temperatures do not increase as rapidly as the boiling points. Frightened by the figures in question, carburetor de-

signers prefer to ignore the considerations, which make it possible to fix the degree of heating the explosive mixture, corresponding to the minimum fuel consumption per horsepower-hour with the heavy substitute fuels, and which can be easily verified by direct experimentation.

Let us note, in passing, that we are limited in the matter of preliminary heating by the temperature of the wall, which must not be too low with relation to the temperature of the mixture at the end of the compression stroke. The action of the wall therefore precludes the use of excessively heavy fuels.

No carburetor designer, to our knowledge, has yet investigated the altimetric correction from the standpoint of heating. Nevertheless, it is very evident that, in rarefied air, it is necessary not only to reduce the fuel intake, in order to maintain the normal composition of the explosive mixture, but also to reduce (other things being equal) the temperature of the gases, before their entrance into the cylinders, by obtaining the same degree of preliminary evaporation.

Since sufficient heat can never be obtained with heavy fuels, it is observed that they behave better (or rather less badly) at high altitudes than near the ground.

Moreover, perhaps even with "white spirits" and coal-tar benzine, surely with the first fractions of kerosene already mentioned, one should have the courage to reduce substantially the compression ratio. It means nothing to diminish greatly

the apparent advance in the spark, because this does not offset the effect of the wall.

We are suffering no illusions. We know that from the viewpoint of heating, we are preaching for the moment in the desert, like our colleague, Mr. Lumet, who stated the rational principle that "the compression ratio should be adapted to the fuel." * The designers are so thoroughly hypnotized by the question of maximum power, which now dominates all engine technics, that they cannot comprehend nor admit the deliberate sacrifice necessary in the magnitude of the engine torque. A still more serious situation is that the inventors of carburetors or carburetants are constantly obsessed with the idea that, on the contrary, the compression ratio could be considerably increased, without heating, by adopting their system. This is equivalent to saying that no one seriously desires to use heavy carburetants or fuels.

By way of compensation, with energetic heating, the back fires to the carburetor can set fire to the safety fuel, heated by conduction, in the float chamber, unless there is inserted, between the float chamber and the intake manifold, some effective device against the retrogression of the flame, like that of our colleague, Mr. Le Grain.

To recall the essential principle of his device, one begins

*See "L'augmentation de la compression dans les moteurs" in the Bulletin de la Société des Ingénieurs Civils," April-June, 1924.

by preparing a very rich mixture, which is easily accomplished with very volatile fuels, and, at a long distance from the float chamber, this mixture is converted into an explosive mixture by adding more air. No flame can enter the tube, which connects the second discharge pipe where the mixture is rendered normal, to the first pipe where the original air is over-carbureted by the fuel delivered to the carburetor nozzle, because the pipe is filled with a noninflammable mixture. Even pieces of wire gauze, occasioning moreover a great loss of charge, would not constitute so sure a barrier, and valves would always function too late.

Safety fuels.— There are two great mineral sources: heavy "white spirits" obtained from foreign (American) petroleum, on the one hand; solvent naphthas (benzine) and rather light tar oils obtained from the destructive distillation of coal, partly of French origin, on the other hand.

Safety fuel or "white spirits." Like most names of complex organic commercial products, "white spirits" cannot be defined simply as a heavy fuel, because the "white spirits" are susceptible of many uses for which the requisite qualities are not identical nor equally strict in all cases.

At our request, the Syndicat des Produits Chimiques (Chemical Products Company) replied that the "white spirits" used as solvents and for diluting oil of turpentine for paints, var-

nishes and polishing waxes must:

1. Be of constant composition, whatever their origin;
2. Have the Engler fractioning characteristics of the 90/160° coal-tar benzine, i.e., distilling between 120 and 180°, 90% distilling at or below 160°C.

The conditions conduce to a flashing point between 25 and 30° (lower than the flashing point of the solvent naphtha II) and to the absence of any residue after evaporation (no grease spot on unglazed paper).

We can only hope that during the course of the discussion, the eventual users of "white spirits" in aviation will be able to satisfy us as regards their own experiences, especially since it concerns a derivative of commercial kerosene, of which only the most satisfactory commercial varieties can be used without rectification, which, as we have shown, would hardly pay.

During the discussion in 1921 on the use of kerosene, we showed a table* in which the carburetants and liquid fuels for explosion and combustion engines were classified according to their volatility. It is shown that these safety fuels are at the limit of the fuels sufficiently volatile to be consumed without great difficulty in engines with the Beau de Rochas-Otto cycle, with spark ignition, and provided with physically heated carburetors. They are likewise quite homogeneous, or, more accurately, quite similar as regards fractional distilla-

*See Bulletin de la Société des Ingénieurs Civils, April-June, 1921, pp. 266-267.

tion. The "white spirits" (a kind of solvent naphtha or benzine) being perfectly pure, it was easily foreseen that they would not cause trouble, like kerosene, in ordinary gasoline engines with the customary compression ratios. It is not the same with certain heavy oils, also called "white spirits" whose distillation begins below 100°C and whose dry point approaches that of kerosene. Without having a wider range of distillation than the "navy" gasolines called "heavy-weight," it would still be necessary to reduce the preliminary compression ratio in comparison with that for good automobile gasolines and especially for benzol.

We will go even further. Without pretending to invent a new fuel, we do not hesitate to claim that, in an engine with a highly heatable carburetor, perfectly regulated for "white spirits," we could use without difficulty the first 35% of ordinary kerosene or the first 45% of the best kerosene, as distilled from the commercial products by the column process. It would not be necessary to reduce again the compression ratio adapted to the "white spirits," but the heating should be increased from $70-75^{\circ}$ to $90-100^{\circ}$. Evidently this obligation to heat the explosive mixture is more troublesome on an airplane than on a boat or truck, where these heavy fuels might also find a logical and economical use.

We might therefore, due to the division of kerosene by redistillation, have an impromptu source of heavy fuels, less in-

flammable than "white spirits" and no more explosive than the "heavy-weight" fuels, i.e., a fuel utilizable in existing gasoline engines which are not supercharged.

Contrary to what one might easily think in advance, the "white spirits" is no more expensive by volume than the "heavy-weight" gasoline. It is even cheaper by weight. As regards such matters, however, it is well to be very prudent. Economic conditions and the need of a supply may change the aspect of the problem.

Solvent naphthas and derivatives of coal tar.— There is no reason why we should not also try the solvent naphthas whose commercial characteristics of distillation serve as the model for "white spirits." Their flashing point, for the same initial boiling point, is rather higher than that of the corresponding "white spirits." Being mixtures of heavy aromatic hydrocarbons (toluene, xylene and cumene) and being incongealable, they form no benzene crystals and they are eminently antidetonant. They need to be heated more, however, than the corresponding petroleum derivatives, because they are less carburetant and have a lower vapor density (Fig. 2). Lastly, they are very expensive.

The solvent naphthas are in great demand as substitutes for oil of turpentine, because their boiling point and density are both near those of turpentine, so that they cost one and a half times the price of "white spirits." On the other hand,

their uses, like those of benzols in general, are very limited.

We cannot extract from tar more than 1% of light oil, not over 90% of which is heavy benzol (excise benzene or excise toluene). If all the tar produced in France in 1926 had been distilled up to 160°C , after preliminary dehydration, and if these first fractions of the tar had all been reserved exclusively for explosion engines, we would have had only $450,000,000 \text{ kg} \times 0.01 \times 0.90 = 4,050,000 \text{ kg}$ of heavy crude benzol. If the distillation of the tar had been carried a little further, we would have been able to collect only $450,000,000 \text{ kg} \times 0.03 = 13,500,000 \text{ kg}$ of refined carbolic oil, half of which, at the most, can be burned in gasoline engines.

It would be too merciless to compare the figures of the fantastic estimates published on our coal-oil resources and especially the real figures of the consumption on hand and to be provided in five or six years for commercial airplanes and for military airplanes and seaplanes in the event of war. Moreover, we will not attempt to convince certain individuals who refuse to consider seriously this question of quantity, available or possible, with relation to our formidable and continually increasing needs.

In the matter of aviation, other reserves are necessary. We cannot recommend the use of carbolic oil and especially naphthaline oils which easily deposit crystals, when very cold, the mixture of which in the atomized state with air, even when heat-

ed above 100°C , does not burn readily without depositing carbon. For all that, they do not contain more carbon than benzene (92.3% carbon, 7.7% hydrogen), but if the automobile benzol can still give complete explosive combustion, although its explosive mixture is never heated to the optimum temperature of $40\text{--}50^{\circ}\text{C}$, the average oil can only cause fouling and black smoke in the exhaust, because no one yet understands that this mixture should be heated to $100\text{--}120^{\circ}$ and more, according to how heavy it is. As regards heavy or intermediate oils and anthracene oil, it is better to reserve them exclusively for combustion engines.

We have shown that greater quantities of "excise toluene" would be found, if aviators should decide to adopt it, by resorting to the benzene removers in coking plants and gas works. It is worse than useless, however, to go to ordinary sellers of such products. The technical aviation departments, if they employ competent advisers and make rational tests, can quickly put in force strict specifications. No one can monopolize this trade. The tar, coke, and gas producers are in position to furnish, under the best conditions, these normal fractions of crude heavy benzol. This is all the more true, due to the present low price of solvent naphtha, whose production increases more rapidly than the demand for its use in paints, where it must compete with the cheaper petroleum products. In our opinion, it is a mistake not to offer "excise toluenes" to aviation, which can become an important customer of the benzol producers.

Limited as the resources in these products are, they can and should be utilized in aviation, but one of the essential conditions for their economical use is the adoption of sufficiently heated carburetors and the avoidance, if possible, of back fires, which are as much to be feared with them as with volatile fuels.

Unfortunately, the rational solution, in conformity with the national economy we have just indicated, would require long investigations and laborious tests followed by a sustained advertising campaign. It is also necessary to await a tardy decision of the skeptical majority, which is impressed with the omniscience of the anonymous delegates of the interested industries and organizations, to adopt the opinion of the regretted manufacturer who prophesied the sale of heavy (and crude) benzol to French automobilists.

Conclusions.-- We have no additions or changes to make in our preceding conclusions, which we will here take the liberty to repeat. We will disregard the question, not yet settled, of combustible liquids which must undergo catalytic cracking "in situ" in order to be used in existing gasoline engines for aircraft.

As soon as the functioning of these engines have nothing to suffer from it, it would seem to be of interest for them to use fuels of a limited volatility according to the Beau de Rochas cycle, ignited by an electric spark, despite the slight

reduction in the maximum power, in the radius of action and in the useful load, resulting especially from the absolute necessity of strongly heating the carburetor and even of reducing the compression ratio in the engine in order to insure efficient combustion.

In fact, the presence, in the tanks of airplanes and seaplanes, of difficultly inflammable fuels, at very high external temperatures on the ground, appreciably diminishes the fire hazards from the fuel carried. However, the harder the fuel is to evaporate, the higher the carburetor must be heated. Consequently, the starting of a fire by back-firing to the carburetor is still to be feared, as with light oils, and reduces the relative safety with respect to the fuel supply on board.

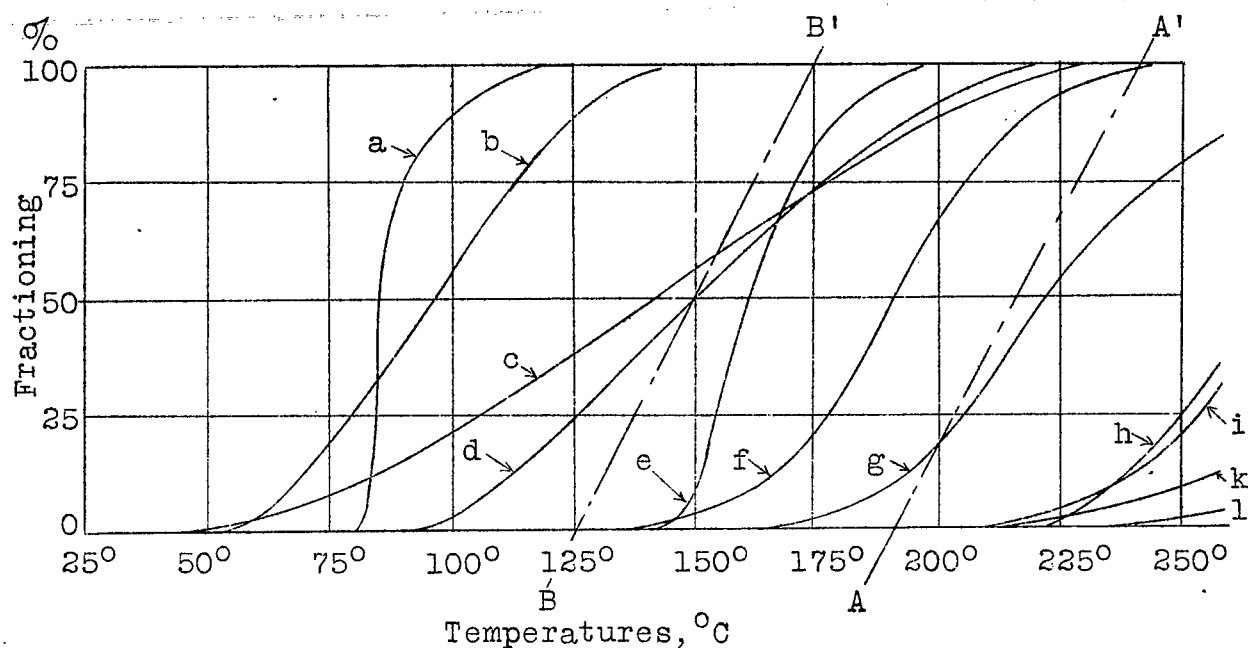
On the other hand, it must be borne in mind that the good functioning of the engine with the heavy fuels is at the mercy of the least misfires, which may entail insufficient heating and especially a deterioration in the lubricating oil by the infiltration of the unburned fuel into the crank case. As we have frequently stated, the investigation of the fuel cannot be separated from that of the engine.

It would be of no advantage to use less volatile fuels in aircraft engines if suitable methods of ignition and safety devices, like the ones preventing back fires to the carburetor, were not simultaneously adopted.

Assuming all these improvements to have been made, it still

remains to convince the chiefs of civil and military aviation, as well as the pilots and mechanics, of the advantages of this change in the fuels. It will be necessary to show them in a practical way that, aside from the performance of sporting stunts, less inflammable fuels than "aviation gasoline" should be used, even at the expense of some reduction in the engine power. This will not be the easiest task of the advocate of safety fuels for aircraft.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.



- a, Engine benzol (-12°C)
- b, Aviation gasoline (-35°C)
- c, Engine gasoline (-30°C)
- d, Light coal oil (13°C)
- e, Safety fuel or solvent naphtha II (40°C)
- f, Carbolic oil from coal (38°C)
- g, Kerosene (50°C)
- h, Gas oil.
- i, Intermediate coal oil.
- k, Heavy coal oil.
- l, Fuel oil.

Fig.1 Fractional distillation of several hydrocarbons.

AA' is the upper limit of the fractional-distillation temperatures of the carburetants. BB' is the lower limit of the fractional-distillation temperatures of the safety fuels. The approximate flashing points are given in parentheses.

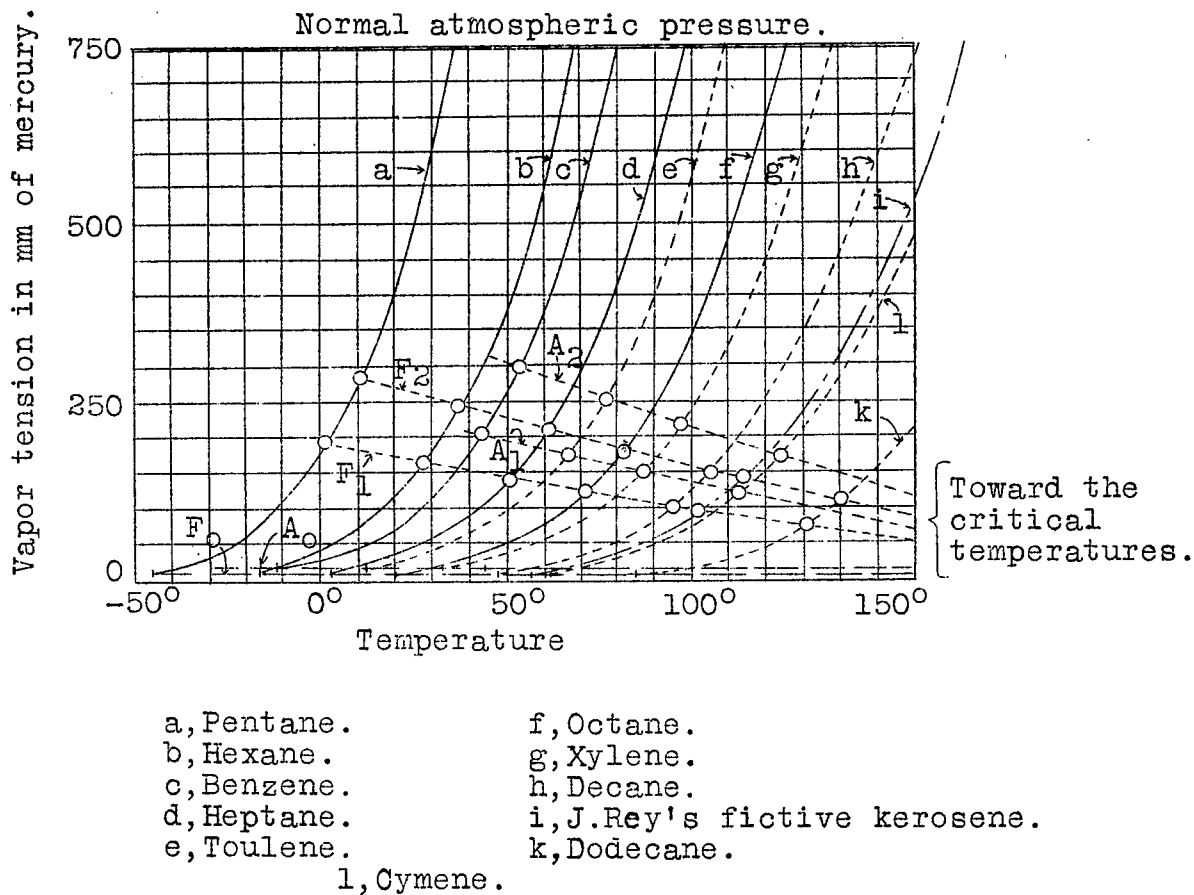


Fig.2 Vapor-tension curves and rational heating temperatures (on the ground) for explosive mixtures of the hydrocarbons C_nH_{2n+2} and C_nH_{2n-6} .

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